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ABSTRACT

We examine the use of RFID (Radio Frequency Id) technology on supply chain management (SCM) systems for a retail store chain. RFID technology may trigger frequent activities in the supply chain such as inventory processing and reordering. We classify the RFID readings according to the transactions they may trigger. We then use the classification to estimate the information processing load rate. A possible application of RFID in retail stores is in shelf replenishment systems. We present a cost benefit analysis for such an application. Our formulas for computing load rates and conducting cost benefit analysis will be of use to information system designers.

KEYWORDS

RFID, Retail Store Inventory management, EPC, Processing Load Rate, Shelf Replenishment Systems

INTRODUCTION

Radio Frequency Identification (RFID) is defined as the use of radio frequencies to read information on a small device known as a tag (Das 2002). A tag is a radio frequency device that can be read by an RFID reader from a distance when there is no obstruction or misorientation. A tag affixed to a product will contain pertinent information about that product. There are two types of tags: passive and active. An active tag is powered by its own battery, and it can transmit its ID and related information continuously. If desired, an active tag can be programmed to be turned off after a predetermined period of inactivity.

On the other hand, passive tags receive energy from the RFID reader and then transmit their ID to the reader. Figure 1 depicts the activity of reading the ID from a passive tag by an RFID reader (Microlise 2003).

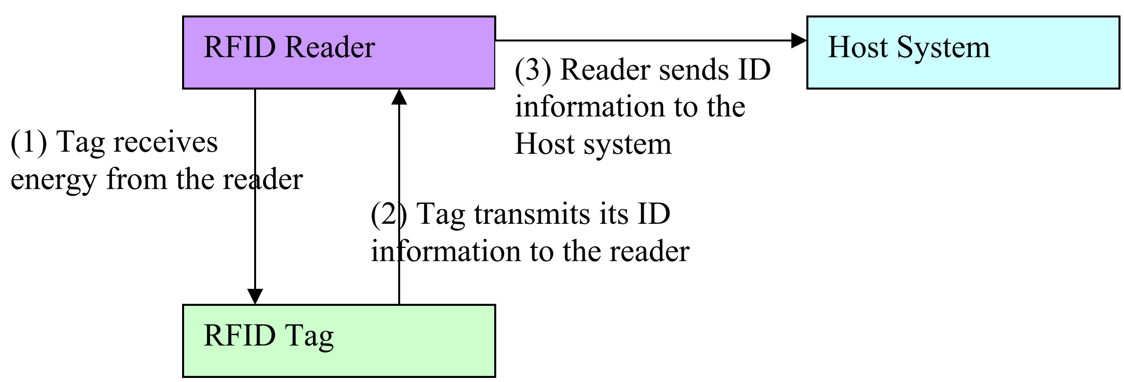

Figure 1: The process of reading the ID information from an RFID tag.

The ID in the above discussion is a unique ID that identifies the product together with its manufacturer. MIT's Auto-ID Center proposed the Electronic Product Code (EPC) that serves as the ID on these tags (Auto-ID Technology Guide, 2002). EPC can be 64 bits or 96 bits long. However, EPC formats allow extending the length of the EPC to be extended in future. Auto-ID center envisions RFID tags constituting an Internet of "things".

RFID tag information is generated based on events such as a product leaving a shelf, or being checked-out by a customer at a (perhaps automatic) checkout counter. Such events or activities generate messages for the host system shown in Figure 1. The host system when it processes these messages in turn may generate messages for other partners in the supply chain. Our research focus in this paper is to study the use of RFID in retail stores for inventory management.

Literature Survey of Traditional Supply Chain Information Systems

Traditional supply chain information systems have been implemented by companies such as Cisco systems, Seven Eleven Japan, Dell, Wal-Mart and Motorola (Grosvenor and Austin, 2001). Several studies have discussed the technical challenges involved in constructing the business-to-business (B2B) supply chain information systems (Pyke et al., 2001, Hewitt, 2001). Mukhopadhyay and Kekre (2002) discuss the strategic and operational benefits of B2B procurement systems. Berkman (2002) points out the need for security measures such as access control and encryption while building B2B supply chain management systems among partners. Weisberg (2002) discusses four different types of information system models for B2B e-procurement systems. One of the models that Weisberg presents is based on virtual private exchanges, to which an organization can subscribe and obtain the latest information on supply, demand and overstock from its partners. Ranganathan (2003) also discusses options for B2B e-exchanges.

Shi and Bennett (2001) discuss several frameworks for managing information systems. These frameworks are divided into four categories: frameworks for identifying IS management issues, frameworks for comparing the IS management issues, frameworks for analyzing the trends and issues, and frameworks for examining the influence of certain factors on IS management. Gunasekaran (2001) mentions the need for IT-integrated benchmarking tools that can provide quick, easy and accurate measurement of the processes that help the business succeed. Aviv (2001) discusses the effects of collaborative forecasting on the performance of the supply chain. His study demonstrates that supply chains can benefit from localized and collaborative forecasting. Prasad and Sounderpandian (2003) discuss various factors that influence the efficiency of global supply chain information systems. Their study discusses various influential factors such as the country characteristics, type of industry and management of supply chains.

Research Contribution of this Paper

Very little research has been done on the processing load generated by the RFID tags in retail store information systems. We first classify the transactions generated by RFID activities into seven distinct categories (Section 3), and then discuss how supply chain information systems can handle these transactions (Section 4). We develop an analytical model for predicting the transaction load, due to RFID activities, on information systems (Section 5). We then model the benefits of RFID in the supply chain. RFID technology can potentially reduce the amount of shelf-space that a retailer needs to maintain; however, RFID implementation incurs cost. We develop an analytical model for analyzing the benefit of reduction in shelf space cost and compare it to RFID implementation cost (Section 6).

RELEVANT FUNDAMENTALS OF SUPPLY CHAIN INFORMATION SYSTEMS

The widespread use of the Internet has prompted companies to manage their supply chains using the Internet as the enabling technology. Internet based supply chains can reduce the overall cost of managing the supply chains, thus allowing the partners to spend more money and effort on innovative research and product development. Internet based supply chains also allow smaller companies to thrive without massive physical infrastructures. In this paper, we discuss the impact of RFID on the Retailer-Supplier interaction in the supply chain.

The information system model for communication between a retailer and a supplier is shown in Figure 2. The retailer is assumed to have several locations, each equipped with RFID readers and RFID-tagged items. Each retailer location has its own computer system comprising a local database of its inventory and application programs that process messages from the RFID tags. The complete inventory information for the retailer is maintained at a central location comprised of high-end database and application servers.

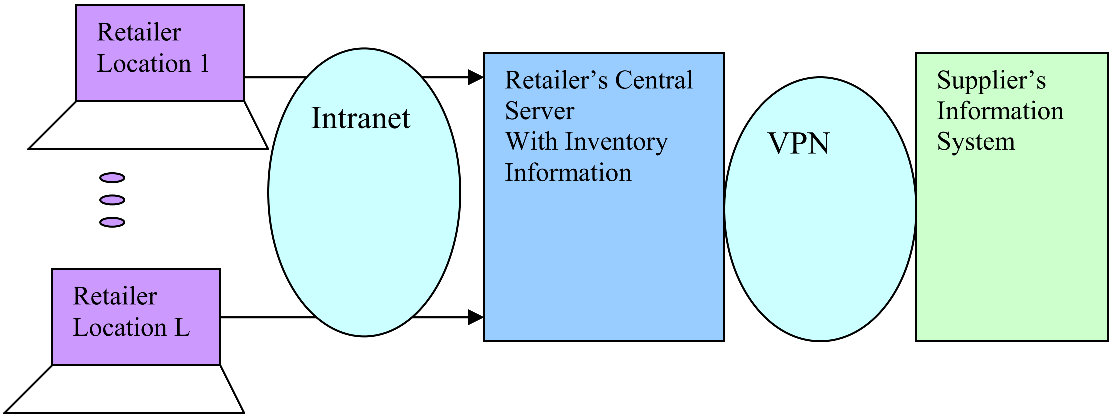

Figure 2: An information system for the interaction between a retailer and a supplier in the supply chain. The retailer is assumed to have L locations, each location with its local inventory information.

Computer systems at the retail locations are interconnected to the central inventory server of the retailer by the company's intranet. Reordering of inventory from the supplier, once inventory levels fall below the reorder points, takes place by communication of specific messages between the retailer's information systems and the supplier's information system. Any such communication is facilitated by a virtual private network (VPN), to which the retailer and the supplier subscribe.

For large retailers, such as Wal-Mart, each location communicating with one central server is impractical. In such case, a hierarchical model of interconnected servers, where each server serves a regional group of locations, is more practical. In this paper, for the sake of simplicity, we assume a flat hierarchy. The ideas and mathematical models developed in this paper can be extended and applied to hierarchical models as well.

CLASSIFICATION OF RFID TRANSACTIONS AT RETAILER LOCATIONS

We classify RFID readings below and mention the transactions that may be triggered upon processing the readings.

Type POS: This is the Point-Of-Sale reading of a tag. An item is checked out by a customer, and its tag is read by RFID. These readings are to be conveyed to the central location where decisions about reordering the item from the supplier and replenishing retail locations are made.

Type SIR: SIR stands for Shelf Inventory Reading. The contents at a particular shelf space meant for a particular item are read by RFID. Within this type, we have the following subcategories.

- *Type SIR1:* One or more items have left the shelf space after the last reading. This type has the following subcategories:
  - *Type SIR11:* The number of items in the shelf has fallen below the reorder point. In this case, a shelf replenishment order needs to be generated.
  - *Type SIR12:* The number of items in the shelf is above the reorder point.
  - *Type SIR13:* One or more misplaced items have been removed from this shelf space.
- *Type SIR2:* One or more items that do not belong in that space are found in the space. These items need to be removed and placed in the correct shelf.

Type SIR3: One or more items have been added to the shelf space after the last reading.

Type SIR4: No change after the last reading.

In the next section, we discuss how these transactions are processed in the retailer-supplier information systems.

PROCESSING OF RFID TRANSACTIONS IN THE RETAILER-SUPPLIER INFORMATION SYSTEMS

RFID readers in the shelves or the checkout counters at retail locations read items with RFID tags. The activities generated by the RFID tags in the retailer and supplier information systems are shown as a series of steps in Figure 3. After the reader reads a tag, the tag together with the location (or ID) of the RFID reader, are sent to the host computer system (Step 1 of Figure 3). The host computer system then requests an object naming server (ONS server) to translate the tag (Step 2). The ONS server is very similar to the domain name server (DNS server) in the Internet that translates web URLs into IP addresses (Auto-ID Technology Guide, 2002).

ONS server accepts a tag as the input and finds out the manufacturer's information and the product information for that tag. This information is transmitted back to the computer system at the retail location (Step 3). Based on the information obtained in steps 1 through 3, the host computer system decides what type of transaction needs be performed (Step 4). From the discussion in the previous section, please recall that the transactions generated by RFID tags are classified into 7 categories: SIR11, SIR12, SIR13, SIR2, SIR3, SIR4. For each transaction, the transaction details are written into a transaction database (Step 5).

The transaction database keeps track of the following information: date, time of the transaction, transaction type, tag that generated the transaction, reader that read the tag, the product information and the manufacturer information. For the POS transactions, the host computer at retail location *i* sends a message to the central inventory server for the retailer (Step 6A).

The central server decides whether the inventory has fallen below the reorder point, in which case, it may reorder the item from the supplier using integrated ERP systems between the supplier and the retailer. The central server may not send reorder transactions instantaneously; it may wait to gather all requests from different retail locations, and generate reorder transactions at pre-specified times. For transactions of type SIR11, SIR12 and SIR2, a message is generated (perhaps by a pager or other electronic means) for the retail store's staff asking them to perform a specific action such as moving a misplaced item to its correct shelf

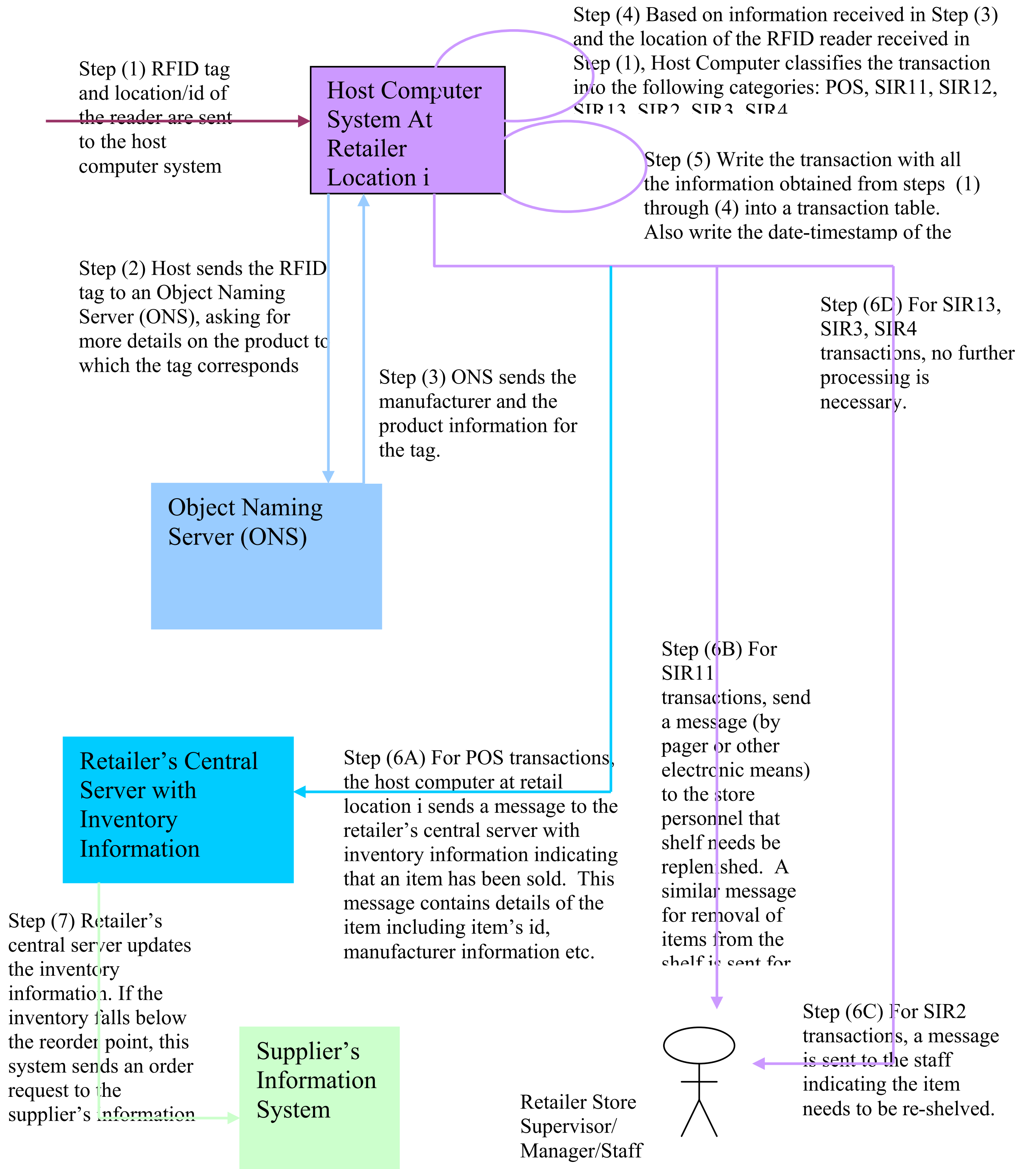

Figure 3: Different activities generated by an RFID tag-read in the information system at the retailer locations and the supplier.

ESTIMATING RFID PROCESSING LOAD

We will use the following notations:

l = Number of retail locations

n_i = Number of items at location i

n = Total number of distinct items at all locations

f_{ij}^{POS} = Frequency of tag reads of transaction type POS for item j in location i

f_j^{SIR} = Frequency of tag reads of transaction type SIR for item j

t_{ij}^{POS} = Processing time required for a POS reading of item j in location i

t_j^{POS} = Processing time required for a POS reading of item j at the central location

t_i^{TYPE} = Processing time required for a SIR reading of item j where TYPE may be any of the subcategories under SIR.

p_j^{TYPE} = Probability the an SIR reading of item j is of a particular TYPE

r_j = Reorder placement rate at the central location for item j. (r_j will indeed be equal to the demand rate of item j divided by its order quantity.)

t_j^R = Processing time for reordering from the central location for item j

We shall compute the POS load rates first.

$$\text{The POS load rate at location } i = \sum_{j=i}^{n_i} f_{ij}^{POS} t_{ij}^{POS}$$

The total POS load rate at the central location is the sum of POS reading load and reordering load. Thus we get,

$$\text{Total POS load rate at the central location} = \sum_{i=1}^{l} \sum_{j=i}^{n_i} f_{ij}^{POS} t_j^{POS} + \sum_{j=1}^{n} r_j t_j^R$$

Next we shall compute the SIR load rates. The SIR loads include the processing times required for the following types of SIR readings: SIR11, SIR12, SIR13, SIR2, SIR3, SIR4. We shall assume the corresponding probabilities of occurrence of these types.

$$\text{Total SIR load rate at location } i = \sum_{j=1}^{n_i} f_j^{SIR} \sum_{TYPE \in \{SIR11, SIR12, SIR13, SIR2, SIR3, SIR4\}} p_j^{TYPE} t_j^{TYPE}$$

We note that p_j^{SIR11} is nothing but the shelf replenishment rate of item j and p_j^{SIR2} is the misplacement rate in the shelf space meant for item j. These rates are very likely to be known and may be substituted in the above expression.

The above formulas can help information system designers to estimate the load rate for RFID installation in retail stores. An important parameter in the above expressions is the frequency of SIR type of readings denoted by f_{ij}^{SIR}. This is a decision left to the information system designers, and therefore an interesting optimization problem. A service level based attempt to optimize this frequency can be found in Gaukler (2004). In the next section, we examine a cost benefit analysis for using RFID for shelf replenishment.

COST BENEFIT ANALYSIS OF RFID FOR SHELF REPLENISHMENT

Consider a retailer who replenishes the inventory on the shelves using the inventory from a back-room. We shall assume that the back-room supply is always available.

In the current non-RFID system for shelf replenishment, an inspector may make rounds on the aisles to see which items on the need replenishment. Assume that this method of replenishing the shelves involves an annual fixed cost F and a variable cost v so that the total cost is $F + vn$ where n is the total number of replenishments in a year. There is always the question about which costs are fixed and which costs are variable. For our purposes here, we shall assume that fixed costs are those that do not change within the range of possible values for n and that the variable cost is linear in n. We also assume the v is constant for all items.

The well-known Economic Order Quantity (EOQ) formula for the basic case implies that EOQ for a particular item j is proportional to the square root of the ordering cost. Thus, the EOQ (which refers to the optimal number of a particular item stocked in the shelf space) before RFID installation is proportional to $\sqrt{v}$. Let the fixed and variable costs be F_{RFID} and v_{RFID} after RFID installation. The new EOQ, denoted by EOQ_{RFID} will then be proportional to $\sqrt{v_{RFID}}$. In other words,

$$\mathrm{EOQ_{RFID}} = \mathrm{EOQ}\sqrt{v_{RFID} / v}$$

which means that the number of units of a particular item brought to the shelf for replenishment will reduce by a factor $\sqrt{v_{RFID} / v}$ due to increased efficiency obtained from RFID installation. We shall next consider the dollar benefit of this reduction.

It is also well-known that the sum of carrying cost and ordering cost over a year for a particular item is proportional to the square root of its ordering cost. The carrying cost here is the cost of the shelf space occupied by the item. If TIC_j is the total annual inventory cost (including shelf replenishment ordering cost and shelf space cost) for item j, then

$$TIC_{RFIDj} = TIC_j \sqrt{v_{RFID} / v} \ .$$

This implies the summation of TC_j over all the items j, denoted by TC, will also reduce by the same factor. Thus,

$$TIC_{RFID} = TIC \sqrt{v_{RFID} / v} \ .$$

The total system cost TSC includes the fixed cost F and the inventory cost TIC. In other words $TSC = F + TIC$. After RIFD installation, we have

$$\begin{aligned} TSC_{RFID} &= F_{RFID} + TIC_{RFID} \\ &= F_{RFID} + TIC\sqrt{v_{RFID} / v} \ . \end{aligned}$$

This means that using RFID for shelf replenishment will be beneficial if

$$F_{RFID} + TIC\sqrt{v_{RFID} / v} < F + TIC$$

or, if

$$F_{RFID} - F < TIC(1 - \sqrt{v_{RFID} / v}\ ).$$

CONCLUDING REMARKS

Despite a large amount of literature on B2B supply chain information systems, there has been no significant work done in the emerging field of RFID technology and its impact on supply chain information systems. RFID tag information is generated based on events such as a product leaving a shelf, or being checked-out by a customer at a (perhaps automatic) checkout counter. Such events or activities generate messages for the computer systems in the supply. Our research focus in this paper has been the impact on the supply chain information systems due to the activities and messages generated by the RFID tags.

We first classified the transactions generated by RFID activities into seven distinct categories, and estimated the processing load rate for a location. We have derived formulas for this estimation. In addition, we developed an analytical model for a cost benefit analysis of using RFID for shelf replenishment in a retail store.

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